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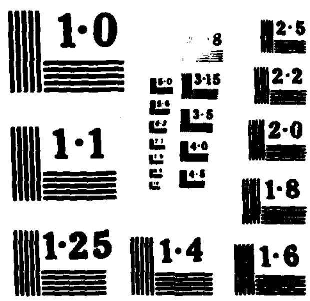
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Characterization of Vapor and Aerosol Flows By Photothermal Methods

by

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Characterization of vapor and aerosol flows by photothermal methods

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Noncontact optical methods are of great current interest in studies of flowing media as they create practically no perturbation. They can easily be applied to hostile environments yielding informations on flow patterns and spectroscopic identification of constituents. Most of these methods rely on Mie scattering from particulates seeded in the flow. These include interferometric methods like laser Doppler anemometry[1] and speckle interferometry[2] or imaging[3] techniques. Coherent Raman scattering techniques[4] can be used to measure velocity, concentration and temperature profiles in pure vapors. We have applied pulsed photothermal heating to flows that are either pure or seeded with aerosols to obtain flow and spectroscopic information . In pure vapors pulsed laser heating creates a thermal lens which is carried away by the flow and probed further downstream by a cw laser. If volatile aerosols are present pulsed heating causes evaporation which can be detected by transient Mie-scattering.

The main parts of our experimental set-up have been shown previously[5]. A Q-switched CO_2 laser beam (pulse duration 1 μs, energy 1 mJ) is focused onto the flow. The absorption of the infrared light by the vapor itself or by aerosols leads to the formation of a travelling thermal lens (TTL) moving with the flow which is probed by a cw laser further downstream as a beam deflection signal. The cw probe beam from a diode laser (λ=780 nm, power 4 mW) is perpendicular to the pump beam for good spatial resolution, which is determined by both focal diameters. In this configuration the thermal lens corresponds to a cylindrical lens[7,8] in contrast to conventional thermal lensing spectroscopy using coaxial probe and pump beams. The probe beam deflection is detected by a photodiode (UDT 600, bandwidth 0-1 MHz) located in the Gaussian wing of the probe beam profile. If aerosols are present, they are detected by their backward Mie scattering using a photomultiplier. Pulsed laser heating of volatile aerosols causes these particles to shrink by evaporation causing a local decrease in Mie scattering intensity in the dense aerosol beam. This is a single-ended technique making it especially attractive for remote measurements. Spatial resolution for aerosol monitoring is usually kept lower

than for TTL gas-flow monitoring to reduce noise caused by particle number fluctuations in the probed volume.

The TTL signal strength as a function of the pump and probe beam offset a is calculated[5] as

$$\phi(t) = \frac{16\alpha E_0(vt-a)}{\sqrt{2\pi}\,(w^2+8Dt)^{3/2}} \exp\left[-\frac{2(vt-a)^2}{w^2+8Dt}\right] \tag{1}$$

where E equals the pump laser pulse energy, w equals the pump laser focal radius, α the absorption coefficient of the medium, v the flow velocity, a the beam separation and D the thermal diffusivity of the medium. Experimental curves obtained for different beam separations are shown in fig.1. The signal decrease is due to the thermal diffusion and can be used to determine the diffusivity D. From the zero crossings the flow velocity can be derived. The width of the signal is determined mainly by the velocity and this can be used to calculate instantaneous velocities , e.g. in turbulent flows. In highly turbulent flows strong density gradients occur causing additional beam deflections. Signal shapes are affected by these gradients and additional work is required for analyzing these signals.

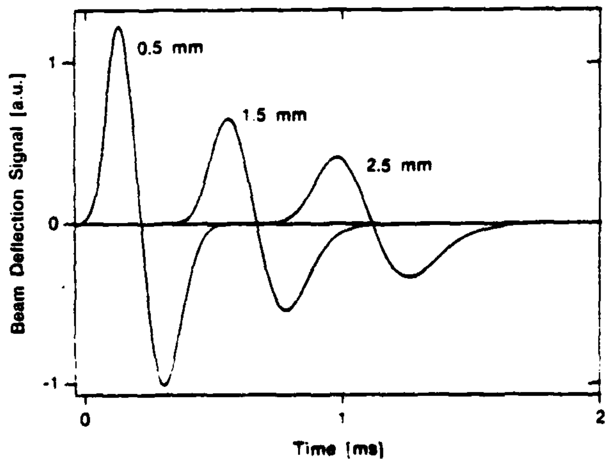

Fig.1: TTL beam deflection signal for indicated beam separations in a nitrogen/ethanol vapor flow.The CO_2 laser is fired at t=0. Signal decrease and broadening is in agreement with eq. (1).

Another set of experiments was carried out on nitrogen flows seeded with water aerosols from a ultrasonic nebulizer. As with the pure vapor, TTL measurements can be obtained from the flow . Flow velocity information is again straightforward, but spectral dependence can now be due to both vapor or aerosol absorption. To determine effects originating purely from the aerosols, backward Mie scattering is monitored. Results for different beam offsets are shown in Fig.2. The widths of these signals is mainly determined by the focal diameters of the pump and probe beam pulses[6] , as long as the duration of pump pulses is short compared to the transit time. Again, from these type of measurements, the aerosol flow velocity can be obtained. For these experiments, pump and probe beams were in the same direction to maximize signal strength. At the pump power level used (2-5 J/cm^2) the aerosols are vaporized almost completely. For large beam separations or slow flow velocity the transient Mie signal becomes smaller and broader, possibly due to recondensation of the supersaturated vapor. As this technique is single-ended with the lasers and the detection system on one side of the flow, this method is especially attractive for remote sensing applications.

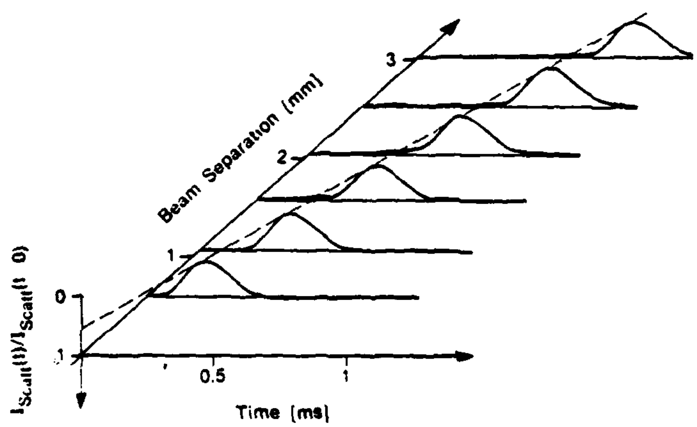

Fig.2: Transient Mie scattering in a nitrogen flow seeded with water aerosols. From the signals at different beam separations the mean flow velocity is calculated to v = 1.59 m/s.

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